International Journal of Engineering Education Vol. 34, No. 4, pp. 1376–1383, 2018
Printed in Great Britain
0949-149X/91 $3.00+0.00

Influences of Learning Competency and e-Learning Implementation on Learning Outcomes of Engineering Students*

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This study examined the combined effects of student learning competency and e-learning implementation on the learning outcomes of engineering students from a series of blended distance education courses. A total of 1,323 valid questionnaire responses were analysed to determine the effects. The results indicated that learning competency comprised two factors, namely scientific literacy and self-regulated learning; e-learning implementation comprised two factors, namely online material guidance and distance teaching quality; and learning outcome also consisted of two factors, namely multidisciplinary learning outcome and fundamental learning outcome. The results also suggested that the scientific literacy and self-regulated learning factors positively predicted the multidisciplinary and fundamental learning outcome factors through the mediators of online material guidance and distance teaching quality. The effects of self-regulated learning and online material guidance on both types of learning outcomes were greater than those that resulted from scientific literacy and distance teaching quality.

Keywords: distance teaching quality; fundamental learning outcome; multidisciplinary learning outcome; online material guidance; scientific literacy; self-regulated learning

1. Introduction

Engineering practitioners are not only required to be competent in particular techniques, but must also be equipped with nontechnical abilities, such as professional ethics, a working attitude, and strong interpersonal communication [1, 2]. In response to an increasingly complex world, the cultivation of multidisciplinary talents within individuals who can communicate across various fields has become a critical concern in engineering education. Because the traditionally discipline-specific educational approach usually fails to facilitate interactions among diverse disciplines, numerous scholars have suggested that multidisciplinary learning should be the primary learning strategy to help learners integrate multifaceted knowledge and broaden their perspectives [3].

Other previous studies have indicated that students' learning outcomes are influenced by various factors, such as learning competency [4, 5], scientific literacy [6], self-regulated learning [7, 8], e-learning quality [9], and learning environment [10]; however, exactly how these factors jointly affect learning outcomes has seldom been examined [11]. There has also been limited research on the effects of these factors between the two learning outcome dimensions, namely multidisciplinary learning outcome and fundamental learning outcome. The multidisciplinary learning outcome refers to the knowledge and skills gained from multiple disciplines that serve to expand beyond a specific-disciplined perspective, whereas fundamental learning outcome refers to the acquisition of general knowledge and skills taught in a course.

Building on previous studies [5, 8], using a different sample, with the discrete research purpose, this paper reports on a study of a series of blended distance education courses from 37 universities in Taiwan. In total, 12 multidisciplinary engineering courses were selected for analysis. A formal learning management system (LMS) was developed with the research staff of the National Center for High-Performance Computing. Each course was required to establish a course website on the LMS, which provided necessary functions, including educational materials, online videos, virtual laboratories, discussion boards, and resource sharing. The courses were delivered once a week through a video-conferencing system across the universities

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* Accepted 20 March 2018.

synchronously. At the end of each semester, all students were invited to evaluate the course and report on their level of agreement toward the effectiveness of e-learning. Using these evaluation reports, this study examined the combined effects of learning competency and e-learning implementation on learning outcomes of engineering students.

2. Literature review

2.1 Multidisciplinary learning in engineering education

Multidisciplinary learning has become one of the main models of modern engineering education. Numerous studies have determined that multidisciplinary learning offers distinct advantages over traditional methods [12]. For example, scholars stated that the holistic performance of university students in multidisciplinary contexts was superior to their monodisciplinary counterparts in innovation, utility, analysis, proof of concept, and communication skills [13]. In addition, Bhandari and associates indicated that multidisciplinary learning teams benefitted students' thinking and comprehension abilities [14]. Because of the significance of multidisciplinary learning, Dederichs et al. suggested that universities should design and offer diverse multidisciplinary courses for engineering students [12].

2.2 Learning competency in relation to learning outcomes

Learning competency refers to the acquisition, selection, and integrated mobilisation of the knowledge, skills, and attitude required for life-long learning [15]. Prior research by Hong compared international efforts to incorporate key learning competencies into school curriculums [16]. One notable learning competency is scientific literacy, which involves knowledge of both science content and science process skills [17] and represents an individual's usage of scientific knowledge to identify questions, acquire knowledge, explain scientific phenomena, and understand scientific features. Although scholars have not agreed on one set of techniques for assessing scientific literacy, Coil and associates claimed that the development of science processing skills, such as data interpretation, experimental design, critical thinking, and research ability, enhances students' scientific literacy [18]. Similarly, Choi et al. stressed that individuals should retain the integrated abilities of understanding science, scientific thinking, and metacognitive skills [18]. To optimise student potential, interest and engagement in scientific literacy should be promoted as early as possible [19].

Self-regulated learning is another crucial learning competency and has been proven to predict learning outcomes and satisfaction [7]. Self-regulated learning is a constructivist learning process in which students are actively engaged in goal setting, progress monitoring, and learning management, rather than passively receiving knowledge from instructors [7]. Research has indicated that self-regulated learning not only directly influences learning outcomes, but also has a mediating effect between rehearsal strategy and learning outcomes [20].

2.3 E-learning implementation in relation to learning outcomes

To enhance the interaction between an instructor and students, video-conferencing has largely been adopted for distance teaching [21]. Through this type of synchronous approach, distance learners receive real-time attention from the instructor, which increases a sense of relatedness, enhances satisfaction with the course, and improves student learning and performance [21]. In addition, considerable attention has focused on developing online materials to promote learning outcomes [22], [23]. Sun and others indicated that e-learning course quality, including course planning, teaching material designs, and interactive discussion arrangements, have the strongest association with learner satisfaction [24]. Sung, Chang, and Yu also stressed the importance of quality online materials in the context of distance education [25].

2.4 Learning competency in relation to e-learning implementation

Investigations into the correlation between scientific literacy and e-learning implementation have also been conducted. For example, Dong and others described their development of online exhibitions in which they promoted public scientific literacy through an extensive application of animation and virtual reality technologies [26]. Chien and Chang later added that the use of learner-paced animation is an excellent way to facilitate students' scientific literacy [27]. In addition, Liu and Chuang suggested that instructors should integrate students' prior scientific knowledge into their teaching and develop various instructional media formats to reduce students' cognitive loads [28].

Self-regulated learning is considered an essential factor in online learning and LMS and is a critical measure of success in these educational contexts [29, 30]. Tsai, Shen, and Fan reviewed studies of self-regulated learning in online learning environments and found that empirical studies on college students' online self-regulated learning had increased from 2003 to 2012 [31]. In an e-learning environment, students can choose their preferred learning process and also have opportunities to practice and apply what they have learned. Therefore, Artino and Jones suggested that an LMS should be user friendly and include online materials that address the importance and value of learning activities [32]. Furthermore, LMSs should provide students with sufficient self-control mechanisms through which they are empowered to engage with their self-regulated learning abilities; Cheng and Chau indicated that self-regulated learning ability is a crucial factor to be successful in e-learning activities [33].

Based on a review of the relevant literature, this study proposed the following hypotheses:

H1: Scientific literacy affects multidisciplinary learning outcomes through e-learning implementation.
H2: Scientific literacy affects fundamental learning outcomes through e-learning implementation.
H3: Self-regulated learning affects multidisciplinary learning outcomes through e-learning implementation.
H4: Self-regulated learning affects fundamental learning outcomes through e-learning implementation.

3. Method

3.1 Participants

A total of 1,710 students from 37 universities enrolled in 12 multidisciplinary engineering courses participated in this study; among them, 1,323 (77.4%) students provided valid questionnaire responses. Because the total data pool was relatively large, two independent samples were randomly drawn to cross-validate the results. First, 261 participants were selected through SPSS to be exploratory samples, comprising 214 males (82%) and 47 females (18%). In total, 79.7% were undergraduate students and 20.3% were graduate students; most students were enrolled as engineering majors (57.9%), followed by electrical engineering and computer science (16.9%), bio-resources and agriculture (4.2%), and science (3.4%). Second, there were an additional 1,062 participants (81.7% male and 17.1% female) selected to be confirmatory samples. Nearly 77% were undergraduate students, and 22.5% were graduate students; engineering majors accounted for the majority of student specialties (60.8%), followed by electrical engineering and computer science (15.1%), bio-resources and agriculture (4.5%), and science (4%).

3.2 Instrument

A course evaluation questionnaire was developed for this study and was completed by each student at the end of the semester. The questionnaire consisted of three scales, including learning competency, e-learning effectiveness, and learning outcome. The learning competency scale was composed of 13 items on a 6-point Likert scale (1 = not proficient at all to 6 = very proficient) to investigate the scientific literacy and self-regulated learning of students. Similarly, the e-learning effectiveness scale consisted of 13 items on a 6-point Likert scale (1 = strongly disagree to 6 = strongly agree) to examine students' attitudes towards course websites, distance teaching, and online material. Finally, the learning outcome scale comprised 15 items for students to self-evaluate their degree of agreement to the learned capabilities after participating in the multidisciplinary online course. The Cronbach α values of the learning competency, e-learning effectiveness, and learning outcome scales were 0.924, 0.949, and 0.954, respectively, which assured internal consistency of the instrument.

4. Results

4.1 Exploratory factor analysis

Exploratory factor analysis (EFA) was conducted using SPSS 17.0 on the exploratory samples (n = 261) to extract the appropriate factor structures for the three scales. Specifically, the principal axis factor analysis with promax rotation was applied to the three scales. All of the factor loadings were greater than 0.40, suggesting that they were appropriate for first-generation surveys.

The EFA results indicated that learning competency consisted primarily of two dimensions, namely scientific literacy and self-regulated learning, which represented 63.6% of the variance. The factor loadings of scientific literacy ranged from 0.504 to 0.883, whereas the loadings of self-regulated learning ranged from 0.670 to 0.951; these values indicated a strong construct validity. Regarding the e-learning effectiveness scale, two key dimensions, namely online material guidance and distance teaching quality, emerged and explained 71.62% of the variance. The factor loadings of online material guidance ranged from 0.678 to 0.925, whereas the loadings of distance teaching quality ranged from 0.515 to 0.863; construct validity was thus established. Regarding the learning outcome scale, two key factors, multidisciplinary learning outcome and fundamental learning outcome, were identified and explained 68.02% of the variance. The factor loadings of the multidisciplinary learning outcome ranged from 0.516 to 0.952, whereas the loadings of the fundamental learning outcome ranged from 0.554 to 0.920; thus, an acceptable construct validity was established.

4.2 Confirmatory factor analysis

Confirmatory factor analysis (CFA) was conducted

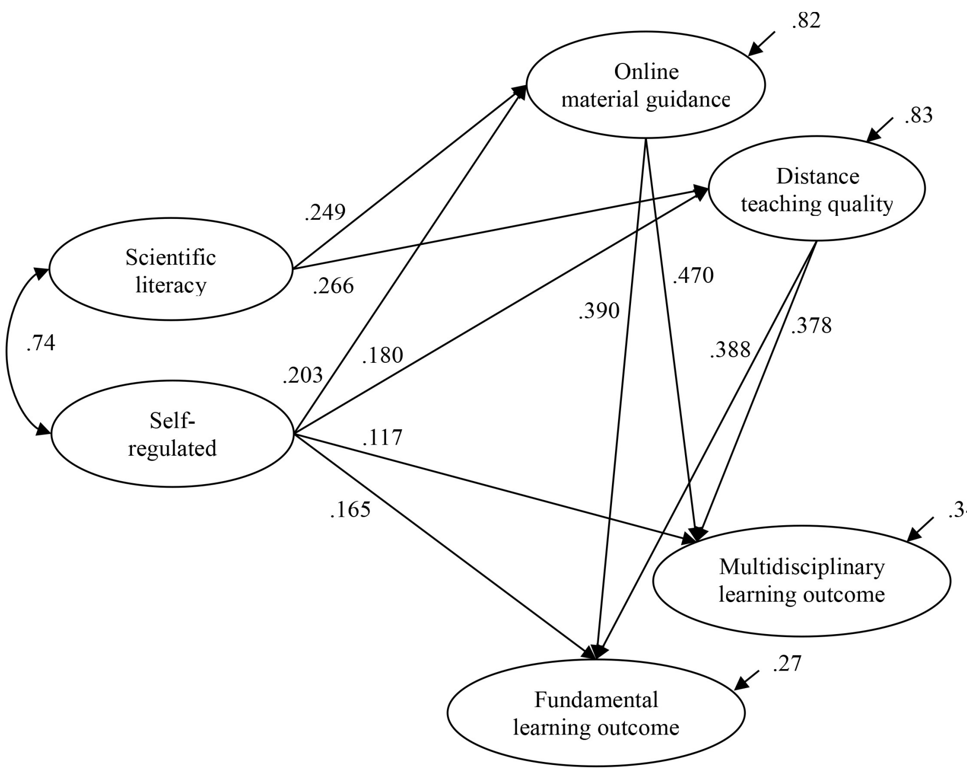

Fig. 1. Mediation model of learning outcome (n = 1,062).

using LISREL 8.70 on the confirmatory samples (n = 1,062) to ensure that the specified factors derived through the EFA adequately matched the data set. The model-fit indices for the learning competency scale revealed an appropriate fit of the model to the data (χ^2 = 553.38, df = 64, p < 0.05, RMSEA = 0.088, SRMR = 0.041, CFI = 0.98, NFI = 0.97, NNFI = 0.97). The confidence intervals between latent variables ranged from 0.7008 to 0.7792, indicating that the factors had discriminant validity. Similarly, the CFAs for the e-learning effectiveness and learning outcome scales also revealed an overall appropriate fit to the data (χ^2 = 2061.30, df = 344, p < 0.05, RMSEA = 0.073, SRMR = 0.032, CFI = 0.99, NFI = 0.98, NNFI = 0.98). The confidence intervals between latent variables ranged from 0.7008 to 0.9196, confirming the discriminant validity of the all the factors.

4.3 Structural equation modeling

To examine the predictive relationships among the proposed constructs, structural equation modeling with a maximum likelihood estimation was conducted using LISREL 8.70 to test the hypotheses. The results revealed that the relationships between the predictive variables (scientific literacy and self-regulated learning) and learning outcomes (multidisciplinary learning outcome and fundamental learning outcome) were significantly reduced when the mediators (online material guidance and distance teaching quality) were included in the model. Therefore, the mediation models were initially supported.

However, although the initial models demonstrated a close fit to the confirmatory samples, not all of the paths were significant. Two nonsignificant paths were removed, and the structural model was subsequently revised (Fig. 1). Notably, the revised model exhibited a fit comparable to the initial model (χ^2 = 3612.179, df = 767, p < 0.05, RMSEA = 0.061, SRMR = 0.044, CFI = 0.98, NFI = 0.98, NNFI = 0.98), and successfully accounted for the substantial variances in each mediator: 18% for online material guidance, 17% for distance teaching quality, 73% for multidisciplinary learning outcome, and 66% for fundamental learning outcome.

As Figure 1 illustrates, online material guidance and distance teaching quality directly predicted both multidisciplinary and fundamental learning outcomes, and scientific literacy indirectly predicted multidisciplinary and fundamental learning outcomes through online material guidance and distance teaching quality; thus, H1 and H2 were supported. Furthermore, self-regulated learning directly and indirectly predicted multidisciplinary and fundamental learning outcomes through online material and distance teaching; therefore, H3 and H4 were partially supported. The results indicated that, in addition to the mediators, self-regulated

Table 1. Direct and indirect effects of the mediation model (n = 1,062)

	Multidisciplinary learning outcome			Fundamental learning outcome		
Latent predictor variables	**Direct**	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
Scientific literacy	–	0.218	0.218	–	0.200	0.200
Self-regulated learning	0.117	0.164	0.280	0.165	0.149	0.314
Online material guidance	0.470	–	0.470	0.390	–	0.390
Distance teaching quality	0.378	–	0.378	0.388	–	0.388

learning is the crucial learning competency factor that influences learning outcome. The direct and indirect effects of the latent predictor variables on learning outcomes are displayed in Table 1.

5. Discussion

5.1 Effects of scientific literacy on learning outcomes through e-learning

The results of this study indicated that a blended distance education approach was an effective instructional strategy for improving learning outcomes. Baker indicated that the immediacy and presence of a live instructor markedly predicted students' learning, cognition, and motivation in a distance educational context [34]; thus, this study ensured that the student participants synchronously received each course lesson through video-conferencing technology from a distant instructor and provided a local instructor in each class who acted as a mentor and monitored the individual learning activities. A coteaching instructional design alleviates the alienation and decreased motivation that are common challenges faced by distance education students.

The effects of scientific literacy on multidisciplinary and fundamental learning outcomes through the mediators of online material guidance and distance teaching quality were also demonstrated by this study. The results mirror the findings of Mbajiorgu and Ali, who argued that no relationship could exist between scientific literacy and academic achievement without the mediator of instructional intervention [35]. Herein, the results implied that students with higher levels of scientific literacy are more willing and motivated to access the online material and engage in distance learning than their less-literate counterparts. With the influence of scientific literacy on students' acceptance and usage of e-learning, their learning outcomes improved as predicted.

Moreover, the total effect of scientific literacy on the multidisciplinary learning outcome ($r = 0.218$) is greater than its effect on the fundamental learning outcome ($r = 0.200$). This finding seems reasonable, given that the development of multidisciplinary professional skills is crucial for students who plan to pursue a scientific career [36, 37], and scientific literacy fundamentally represents the interwoven threads of multidisciplinary knowledge [38]. This result also corresponds with the argument of Correia et al. that school curriculums should overcome the traditional fragmentation of knowledge into diverse disciplines [39]; these scholars noted that scientific literacy objectives are only achieved through the integration of science, technology, society, ethics, and the environment. Similarly, Cook, Druger, and Ploutz-Snyder suggested that undergraduates with high scientific literacy had greater multidisciplinary knowledge, and expressed favourable attitudes towards a broad range of science-related issues [40].

Notably, the mediating effect of online material guidance ($r = 0.117$) was greater than that of distance teaching quality ($r = 0.101$) on the relationship between scientific literacy and the multidisciplinary learning outcome; however, the mediating effect of distance teaching quality ($r = 0.103$) on the fundamental learning outcome was greater that of online material guidance ($r = 0.097$). These results can be elaborated twofold. First, the effect of scientific literacy on distance teaching quality was slightly greater than that on online material guidance, which implies that the instructional methods should be modified in accordance with students' knowledge base. For example, students who tend to actively participate in learning activities, and interact with instructors and peers alike, should receive immediate responses and approving feedback. Second, students may not have sufficient time to engage in multidisciplinary learning in a real-time course; thus, developers of online material should focus on integrating multifaceted perspectives and approaches where possible.

5.2 Effects of self-regulated learning on learning outcomes through e-learning

This study indicated that self-regulated learning both directly and indirectly influences multidisciplinary and fundamental learning outcomes through the mediating effects of online material guidance and distance teaching quality. These findings verify prior research [41, 42] and suggest that self-regulated learning is an effective means to improve academic performance. Distinct from scientific literacy, the total effect of self-regulated learning on the fundamental learning outcome (r = 0.314) is greater than that on the multidisciplinary learning outcome (r = 0.280). More critically, these results contribute to an understanding of the predictive relationship between self-regulated learning and fundamental learning outcomes. To implement fundamental courses in an e-learning environment, engineering educators may need to focus on the design of learner control mechanisms and allow students to explore a variety of topics and practise what have learned in diverse situations. In particular, these designs must be user friendly and address the values of fundamental learning [32].

Moreover, the present results further validated arguments that instructional interventions have a substantial effect on the relationship between self-regulated learning and learning outcomes [43]. Zhao et al. argued that the application of self-regulated learning in distance teaching is a newly emerging area [44], and Greene, Hutchison, Costa, and Crompton indicated that fostering self-regulated learning abilities should be a key issue at all levels of distance education [45]. Although some studies [46–48] have suggested that self-regulated learning is rarely associated with learners' problem solving, concept mapping, or knowledge growth, Tsai et al. demonstrated that students who excel at self-regulated learning would outperform their counterparts over the long-term [24]. Cheng and Chau also noted that metacognitive control strategies (i.e., self-regulated learning) positively correlate with students' e-Portfolio achievements [33]. The present study concluded that the notable role of scientific literacy on multidisciplinary learning outcomes, and of self-regulated learning on fundamental learning outcomes, implies that engineering educators should consider multiple student combinations to achieve various learning aims.

5.3 Online material guidance and distance teaching quality

According to the present study, the effect of online material guidance on the multidisciplinary learning outcome (r = 0.470) was greater than its effect on the fundamental learning outcome (r = 0.390). By contrast, the effect of distance teaching quality on the fundamental learning outcome (r = 0.388) was slightly greater than its effect on the multidisciplinary learning outcome (r = 0.378). The marked roles of online material guidance on the multidisciplinary learning outcome, and of distance teaching quality on the fundamental learning outcome, implies that engineering educators should consider a range of instructional interventions to achieve various learning aims; furthermore, these results also elucidated the distinct mediating effects between predictive and outcome variables, and provided insight into the domains and settings that require different learning outcomes.

5.4 Research limitations

Although this study extends prior research in multiple ways, it is not without limitations. First, the learning competency and learning outcomes in this study were self-perceived, and because the questionnaire items were not considered personally sensitive, participants' responses may have been coloured by social desirability bias. Second, online material guidance and distance teaching quality are only two considerations of an e-learning context; other variables such as student attributes, interaction preferences, and instruction effectiveness should be examined in future research to further clarify the effects of these two factors. Finically, this study did not examine the opinions of instructors or mentors. The potential influences of instructors and mentors' attitudes on the students' attitudes toward blended learning and perceived learning effectiveness should be explored in the future.

6. Conclusions

In a blended distance education approach, scientific literacy influences multidisciplinary and fundamental learning outcomes through the mediators of online material guidance and distance teaching quality. Moreover, the effect of scientific literacy on the multidisciplinary learning outcome is greater than its effect on the fundamental learning outcome. In addition, self-regulated learning both directly and indirectly influences multidisciplinary and fundamental learning outcomes through the mediating effects of online material guidance and distance teaching quality. Furthermore, the effect of self-regulated learning on the fundamental learning outcome is greater than its effect on the multidisciplinary learning outcome.

Notably, because this study analysed relatively large samples, the findings are somewhat generalisable to the larger population. Furthermore, consistency between the EFA and CFA results indicated that the factor structures of the measures are stable across the sample groups, and no indications of self-reporting bias were observed. Overall, although the findings of this study have begun to address a large gap in the research, continued research is necessary to accurately understand blended learning, distance education, and the numerous factors that affect these concepts.

Acknowledgements—The authors thank Taiwan Ministry of Science and Technology (MOST 103-2628-S-002-002-MY2) for their grant that partially support this study.

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